BTeV-doc 750

Lepton, Hadron and Photon Identification at BTeV

Rob Kutschke

Fermilab

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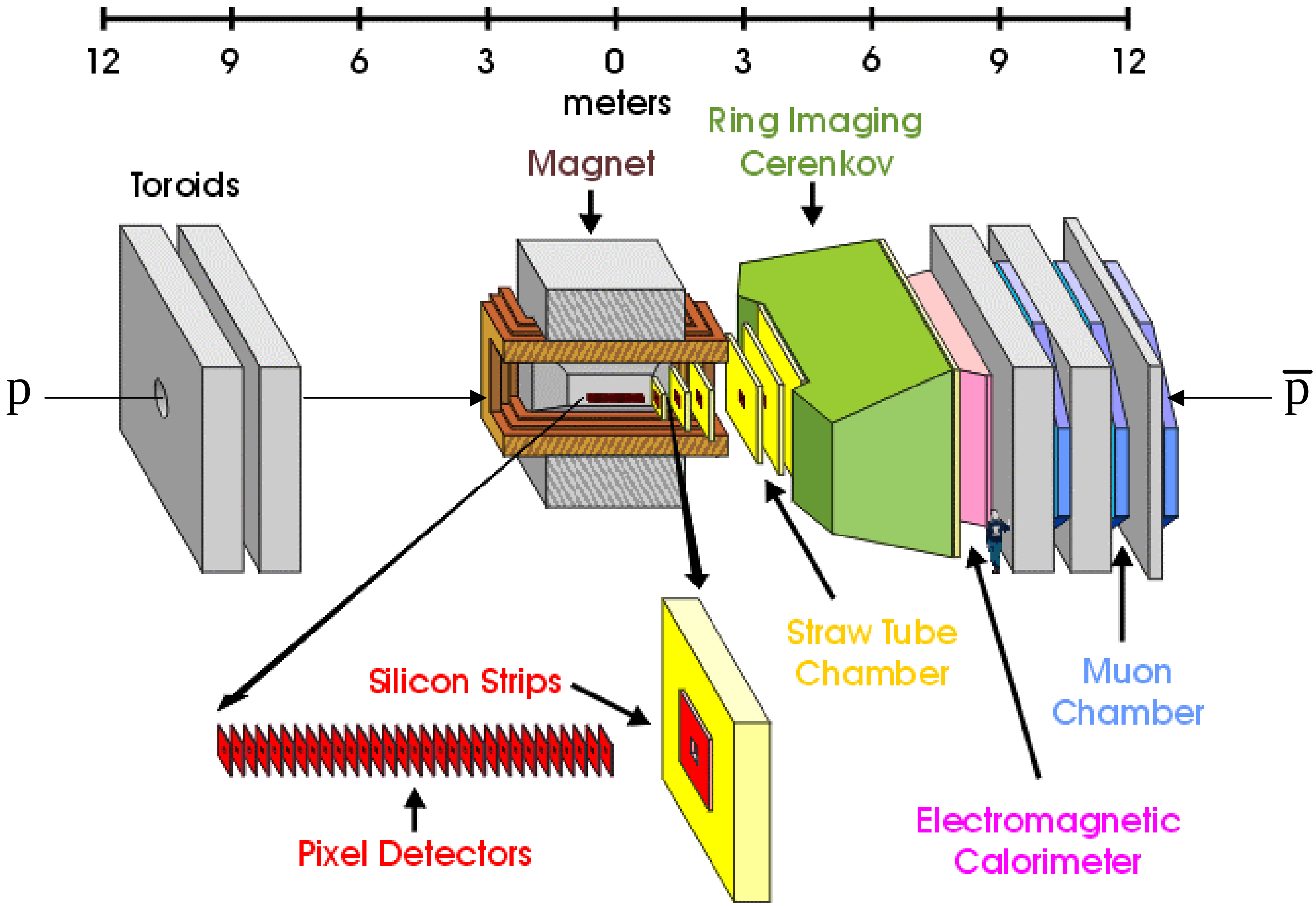
What is BTeV?

- At the Tevatron p-$\bar{p}$ collider, at Fermilab:
  - Forward spectrometer.
  - Beauty and charm physics:
    - Precision measurements.
    - Search for rare and forbidden phenomena.
- BTeV is a part of broad program to address fundamental questions in flavor physics.
- For more details: http://www-btev.fnal.gov/
  - 4 talks at Beauty02: Kutschke(2), Butler, Newsom.

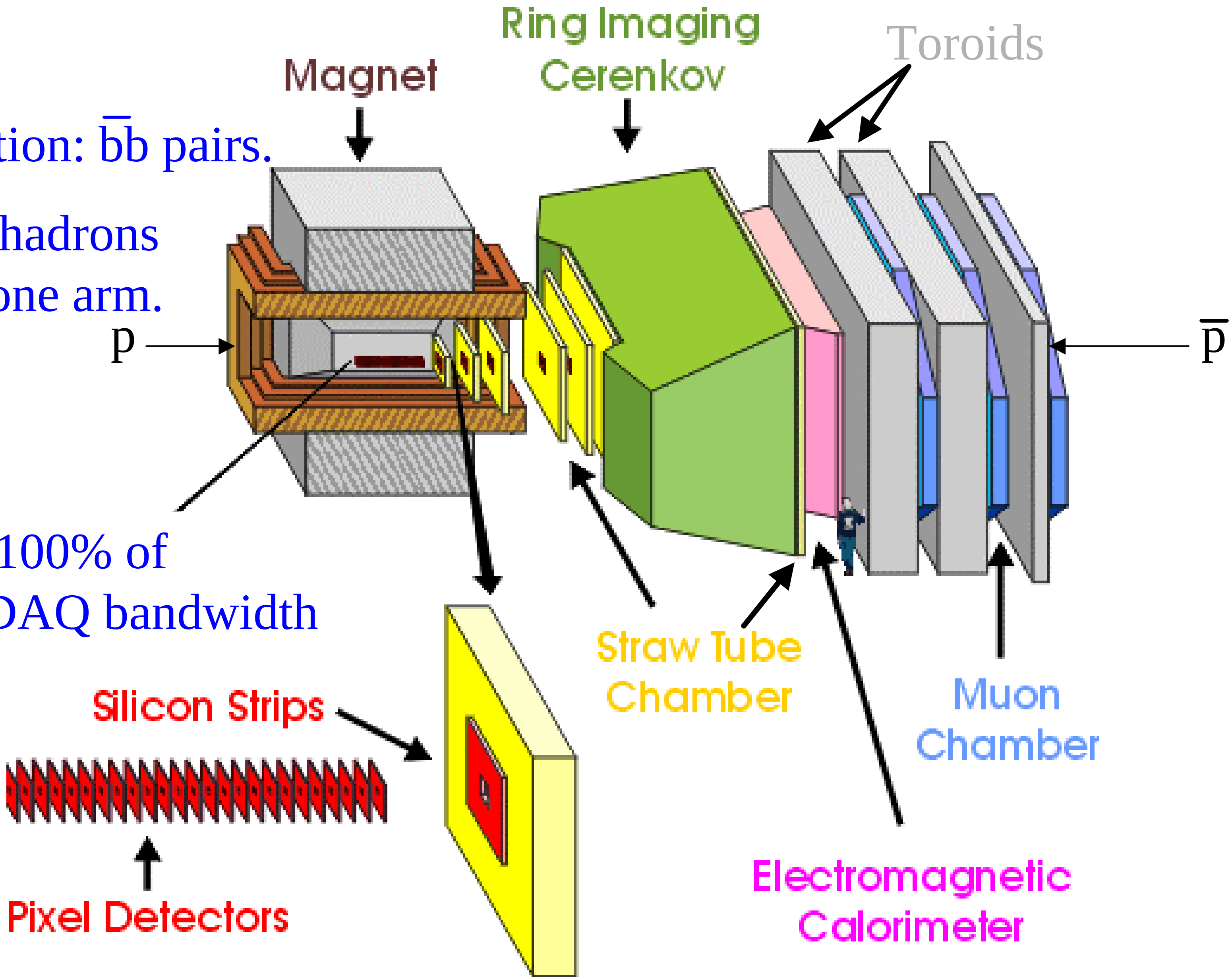
BTeV Detector Layout



•Production: $b\bar{b}$ pairs.

•Both b hadrons go into one arm.

•Retain 100% of trigger/DAQ bandwidth



Particle ID

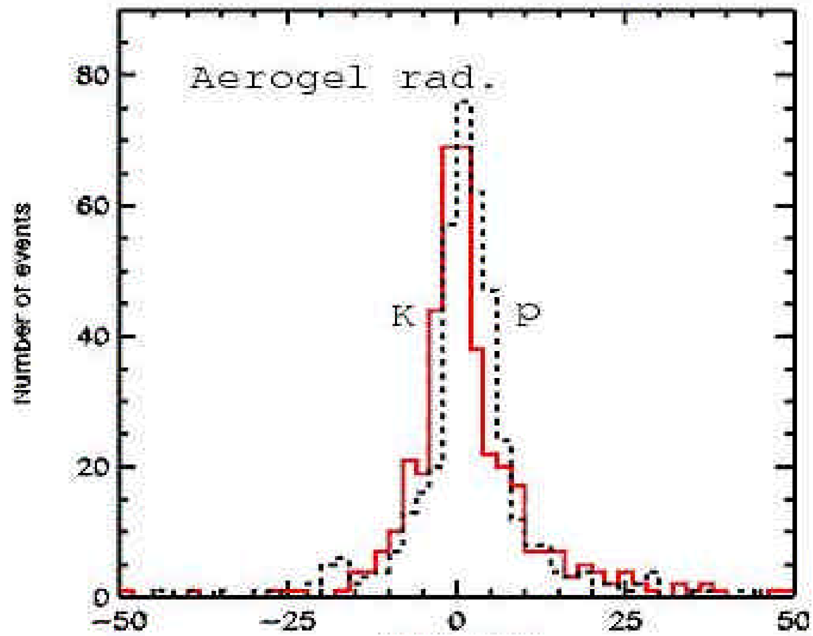
- Two critical roles:
  - To reduce combinatoric background signal channels.
    - Eg distinguish $B^0 \to \pi^+\pi^-$ from the more copious $B^0 \to K\pi$.
  - Flavor tagging.
- Charged particle ID makes use of: RICH, EMCal, and Muon systems.
- This talk also includes γ and π^0 reconstruction in the EMCal.

Ring Imaging Cherenkov Counter (RICH)

- Two radiators: to cover desired momentum range.
  - Original design: gas C_4F_{10}, aerogel.
  - One array of Hybrid PhotoDiodes (HPDs) for both.
- Aerogel has proven inadequate:
  - Large, diffuse rings with too few photons, lost in gas rings.
  - Thicker aerogel limited by scattering in bubbles.
- New solution:
  - Liquid C_5F_{12}: very large angle rings.
  - Rings do not overlap with gas rings. Separate readouts.
  - Readout by PMTs on the sides of the gas box.

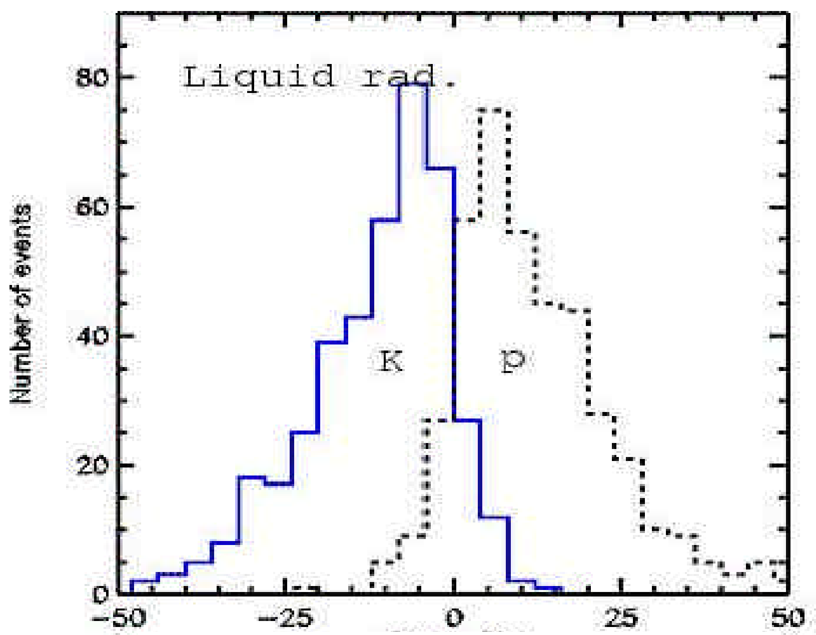
Before and After: K/p Separation

Aerogel



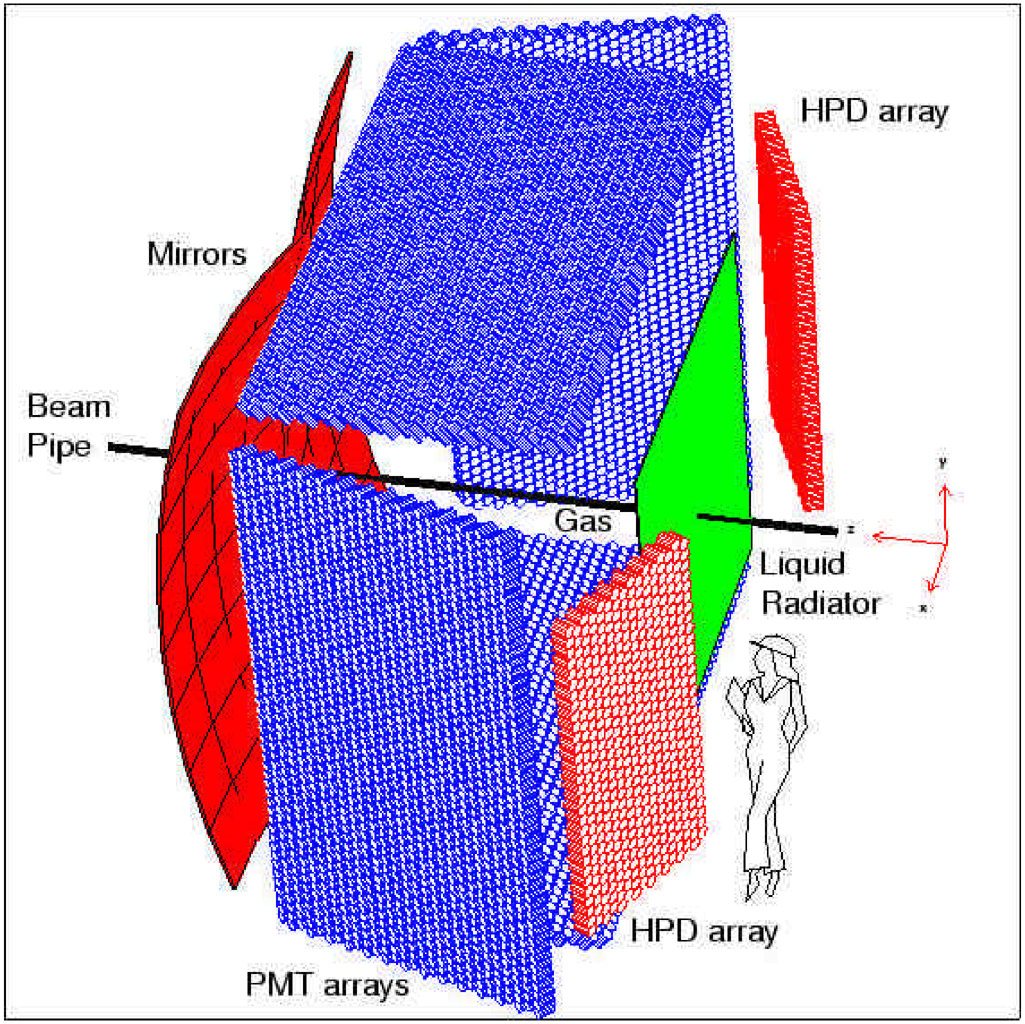
$\chi^2(K) - \chi^2(p)$

C_5F_{12}



$\chi^2(K) - \chi^2(p)$

New Layout of the BTeV RICH



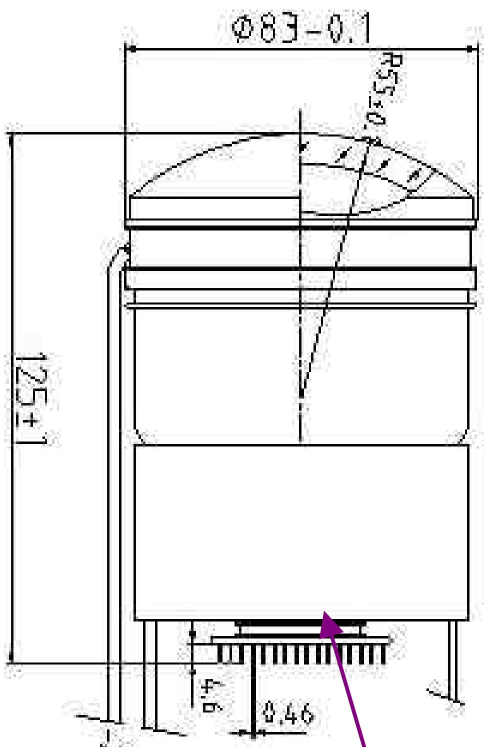
• PMTs do not need quartz windows. Borosilicate glass OK.

Tracks from IR

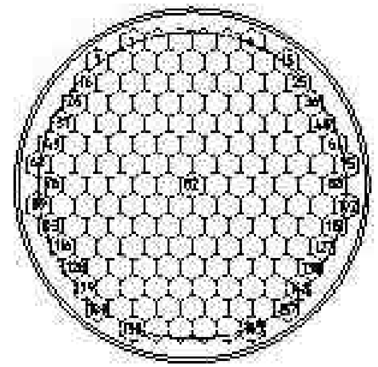
•PMT costs partly offset by reduced size HPD arrays.

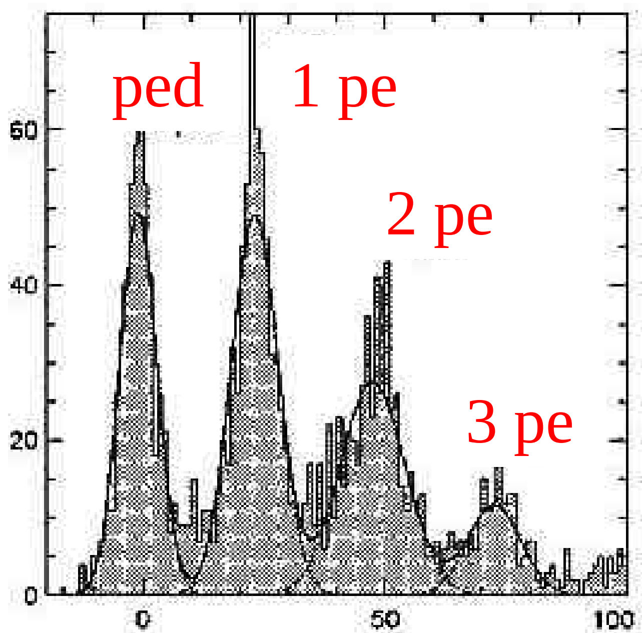
HPD Schematic

HPD Tube

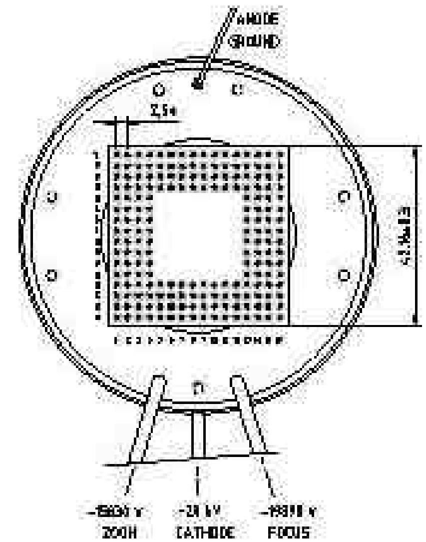


HPD Pixel array





HPD Pinout

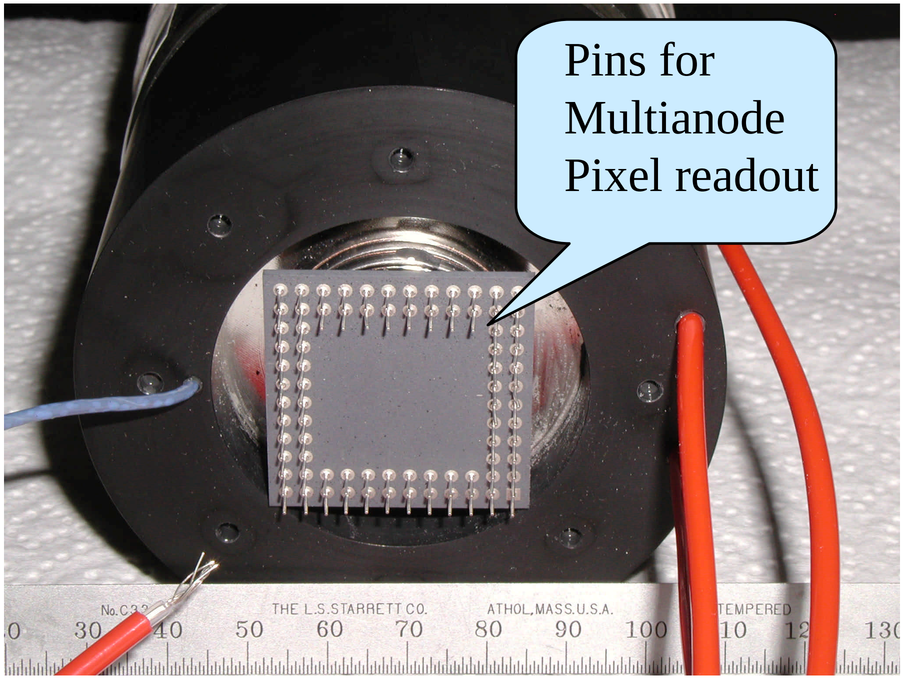


Pulse Height from 163 pixel prototype HPD, using old CLEO electronics. Note pedestal, 1, 2, 3 pe peaks.

HPD Photos

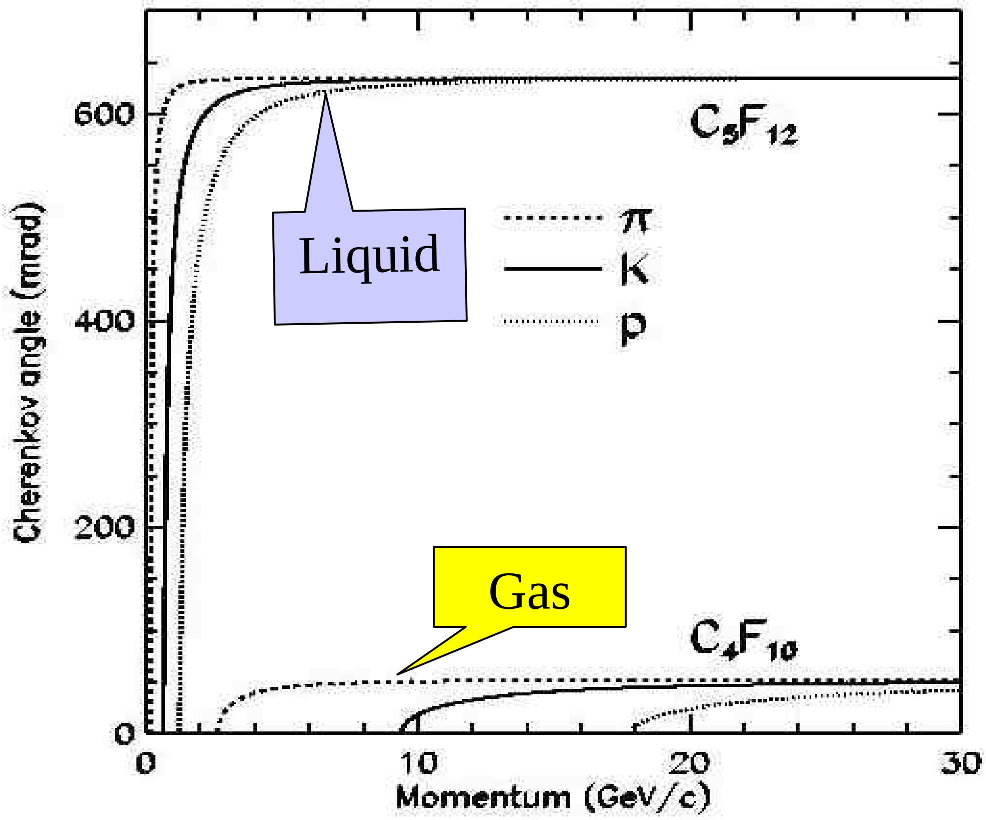
Photocathode

Readout



- 61 channel HPD shown (we have in and will use 163 channel HPD).
- Pins through the glass envelope connect pixels to the electronics.
- Backup solution: Hamamatsu R7600 M16 Multianode PMT.

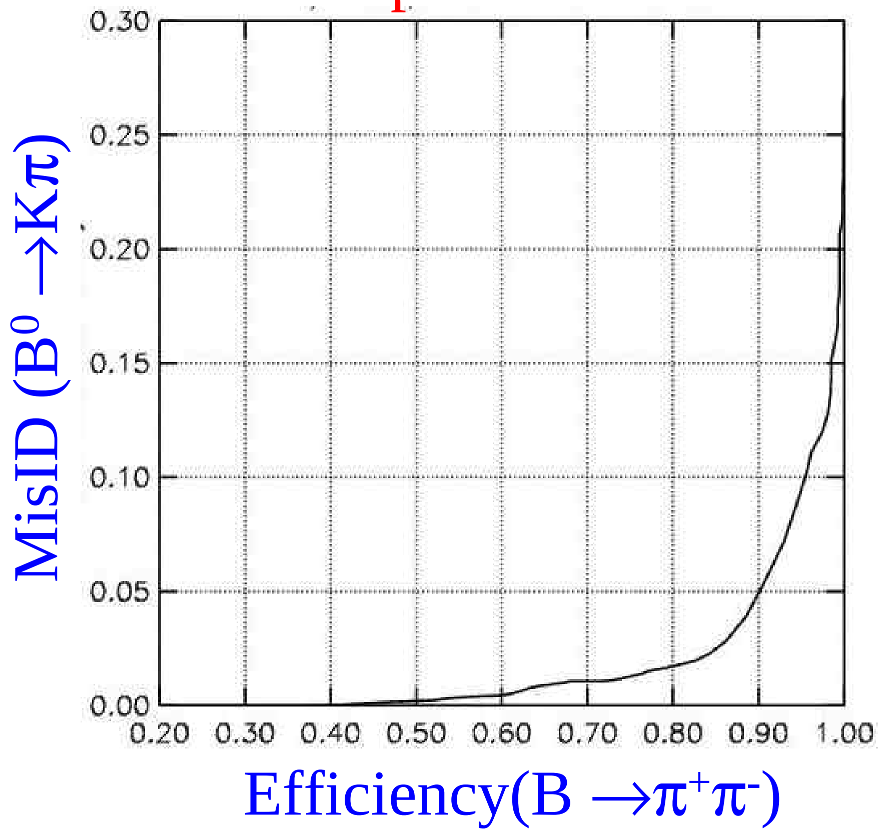
Cherenkov Angles in the BTeV RICH



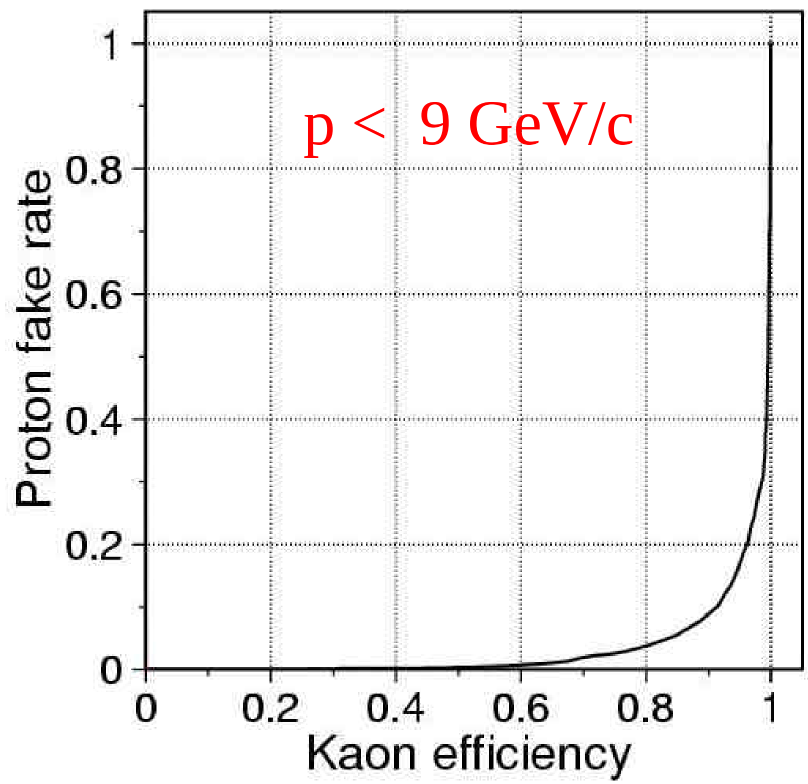
- If only the gas radiator, then for p < 9 GeV/c:
- No K/p separation
  - Hurts kaon tagging.
- K/π sep. is threshold only
  - Every badly reconstructed track is a kaon!
  - Hurts kaon tagging.
- For 9 < p < 18 GeV/c, K/p separation is threshold only.

Geant 3 Simulation of RICH Response

K/π Separation in Gas

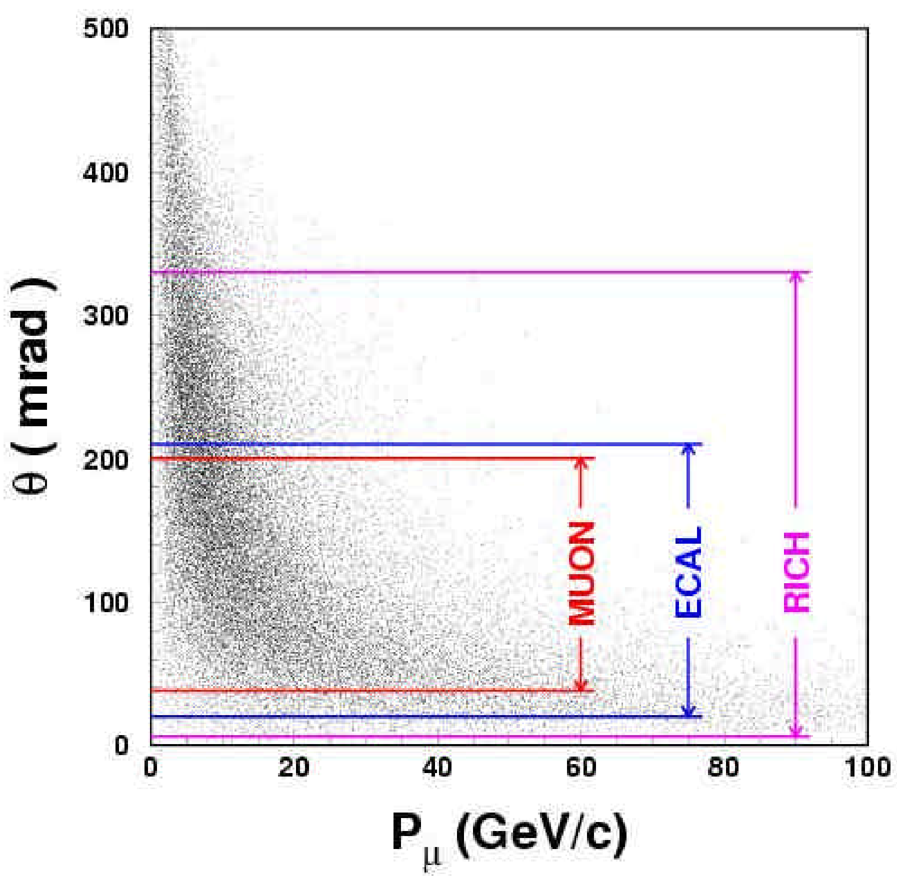


K/p Separation in Liquid



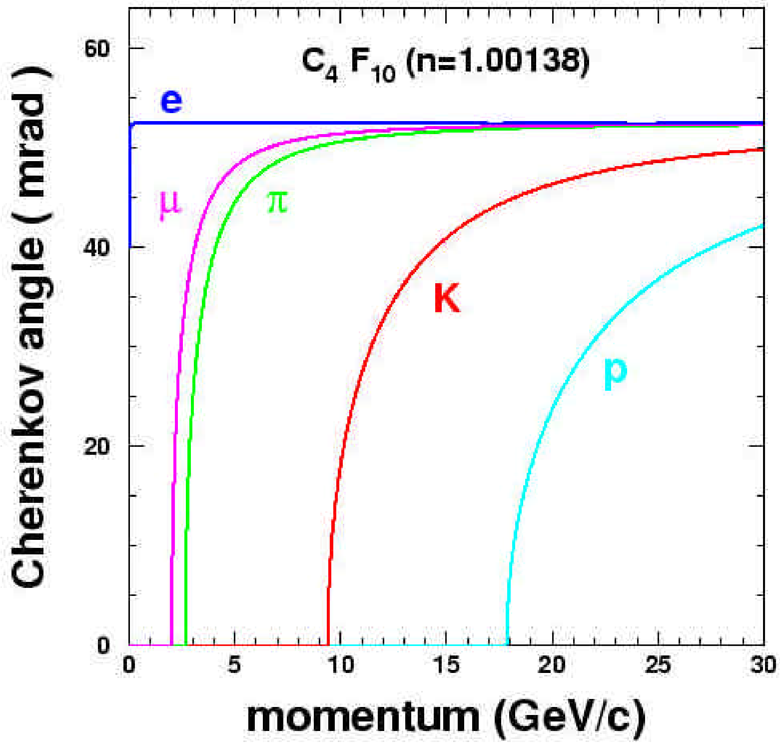
Using the RICH for Lepton ID

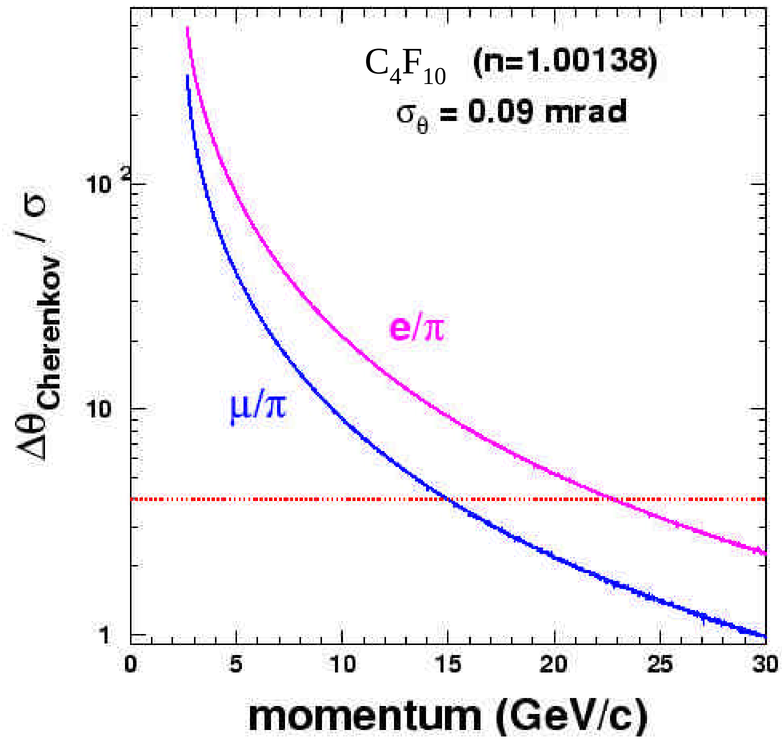
- Many leptons which miss the Ecal and Muon systems are accepted by the RICH.
- These leptons are at low momentum where RICH has lepton ID power.
- Perfect match!



Leptons from B decay

RICH has e-π and μ-π Discrimination!





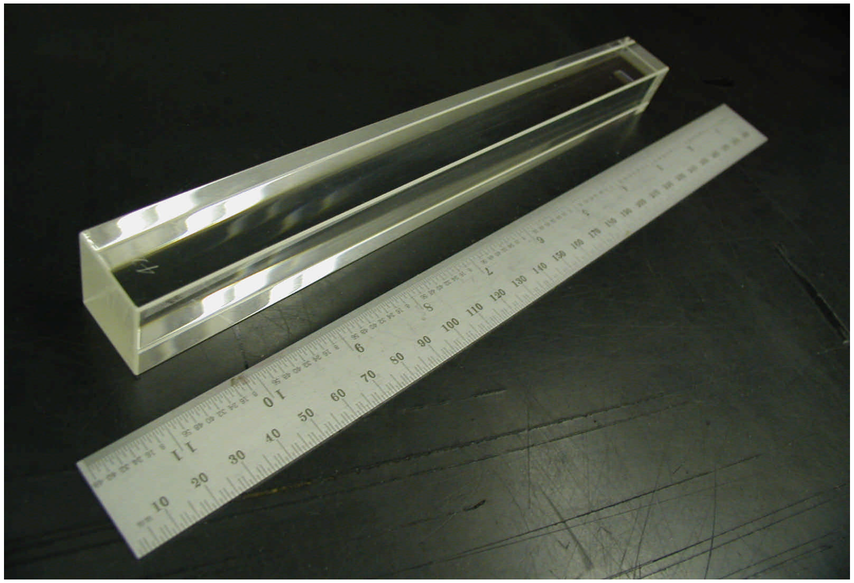
- Wide angle particles are mostly low p. Perfect Match!
- Efficiency: ×2.4 (×3.9) for single (double) lepton ID.

Miscellaneous RICH Issues

- PMTs and HPDs will be in a region of low but non-zero B field.
  - Now testing shielding options.
- Mirror options:
  - Glass
  - Glass + composite
  - Composite Replica
    - Test pieces for first two will be available for the fall 2002 test beam run.
- Mechanical, cooling, electronics underway.

Electromagnetic Calorimeter

- Projective geometry crystal calorimeter.
- $PbWO_4$: for $\sigma(E)$ and for radiation hardness (like CMS).



Block from Shanghai Institute of Ceramics

5X5 stack of blocks from Bogoriditsk.

- Also evaluating crystals from Beijing and Apatity.

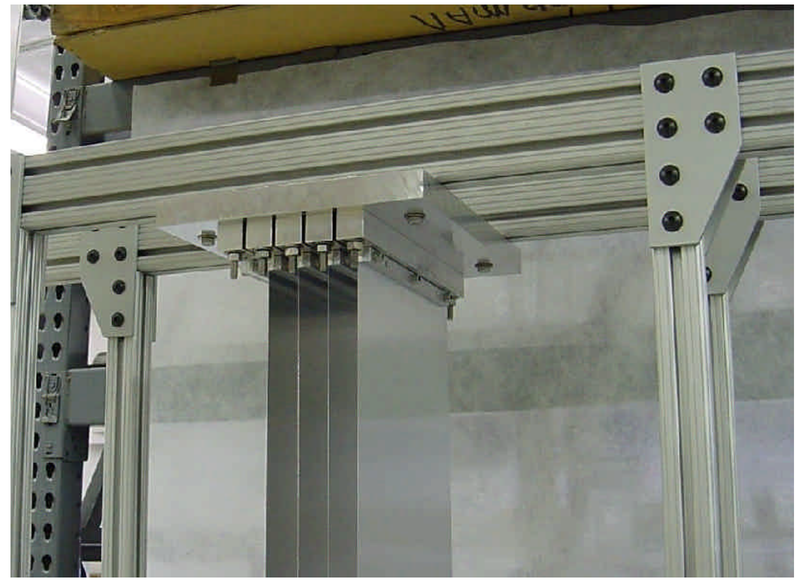
Electromagnetic Calorimeter

Properties of $PbWO_4$	Value
Density (g/cm^3)	8.28
Radiation Length (cm)	0.89
Interaction Length (cm)	22.4
Light Decay Time (ns) (39%)	5
(60%)	15
(1%)	100
Refractive Index	2.30
Maximum of emission (nm)	440
Temperature Coefficient (%/^{o}C)	-2
Light Output/NaI(Tl) (%)	1.3
Light Output (pe/MeV into a 2" PMT)	10

Properties of BTeV Calorimeter	Value
Block cross-section: back (mm^2)	28.0×28.0
front: (mm^2)	27.2×27.2
Block Length (cm)	22
(Radiation Lengths)	25
Front end electronics	PMT
Digitization	QIE (FNAL)
Square beam hole (cm^2)	$\pm 9.88 \times \pm 9.88$
Outer "radius" (cm)	160
Blocks/arm	10500
Polar angle (mr)	± 200

- CMS uses avalanche photodiodes(barrel) and triodes(endcap) because their readout is inside B field. We will use PMTs.

Mock Up of Mechanical Design

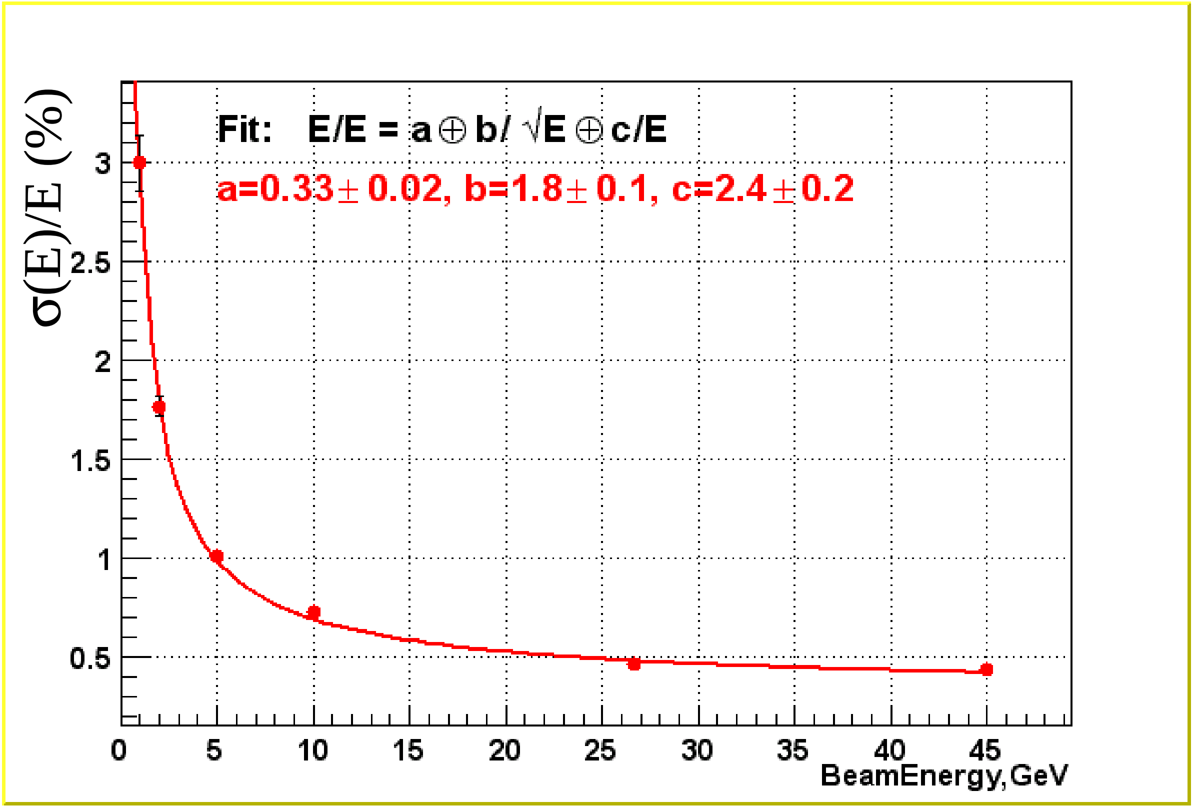


- To help estimate cost and schedule.
- Basic design: super-crystals.
- Target material is carbon fibre.
- Cooling design also underway.

EMCal IHEP Test Beam Program

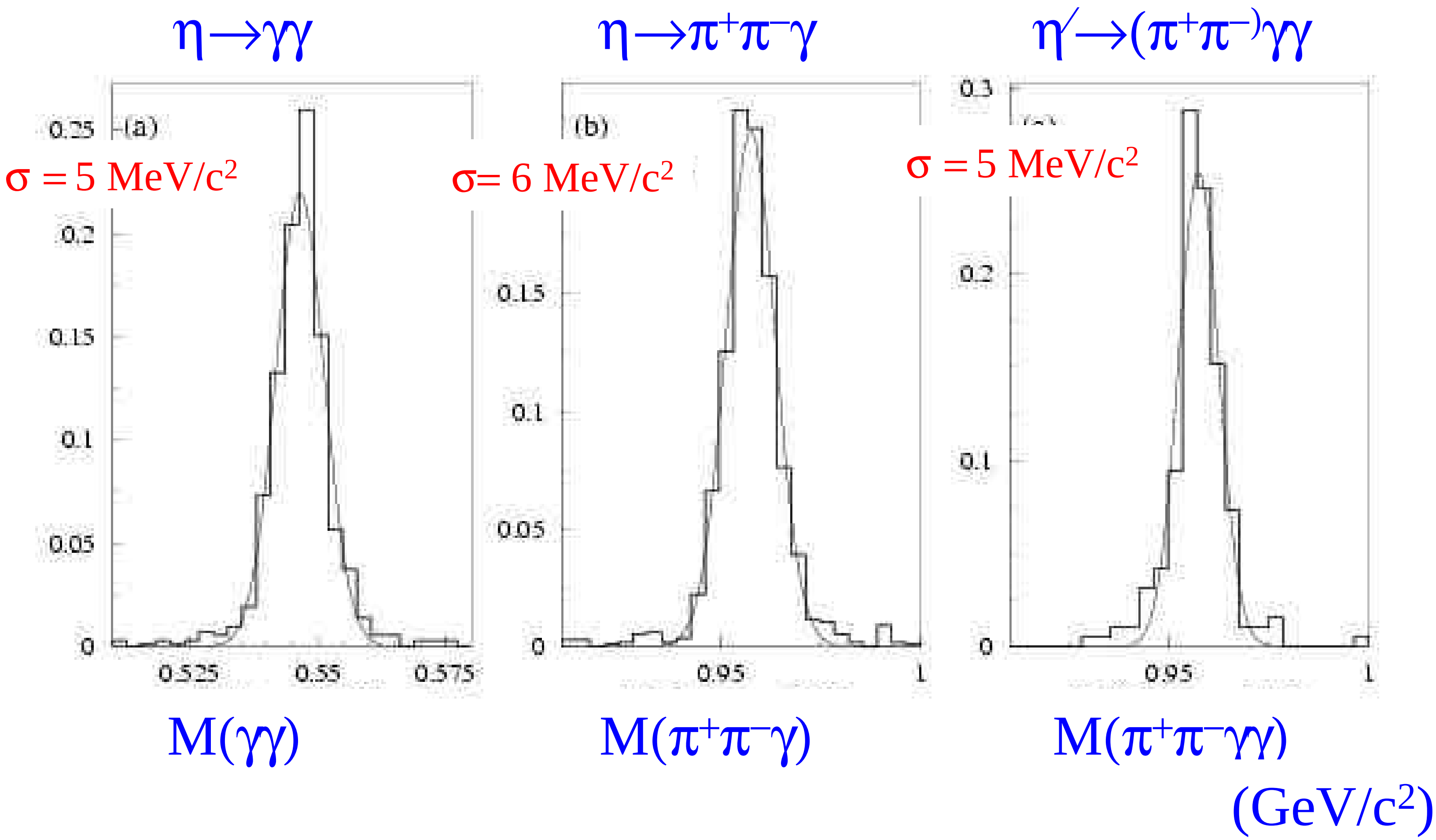
- IHEP Protvino: Dec/00, Mar-Apr/01, Nov-Dec/01, Mar-Apr/02. Request for Nov-Dec/02.
  - Electron and pion beams (momentum measured).
- Study vs incident energy, position and angle:
  - $\sigma(E)$ with different crystal wrappings.
  - Time, temperature and rate stability.
  - Radiation hardness and recovery.
    - Realistic dose rates and artificially high dose rates.
- Used 10 stage tubes in tests, will use 6 stage in BTeV.
  - 6 stage + QIE chip almost identical to KTeV.

σ(E) Measured in IHEP Test Beam

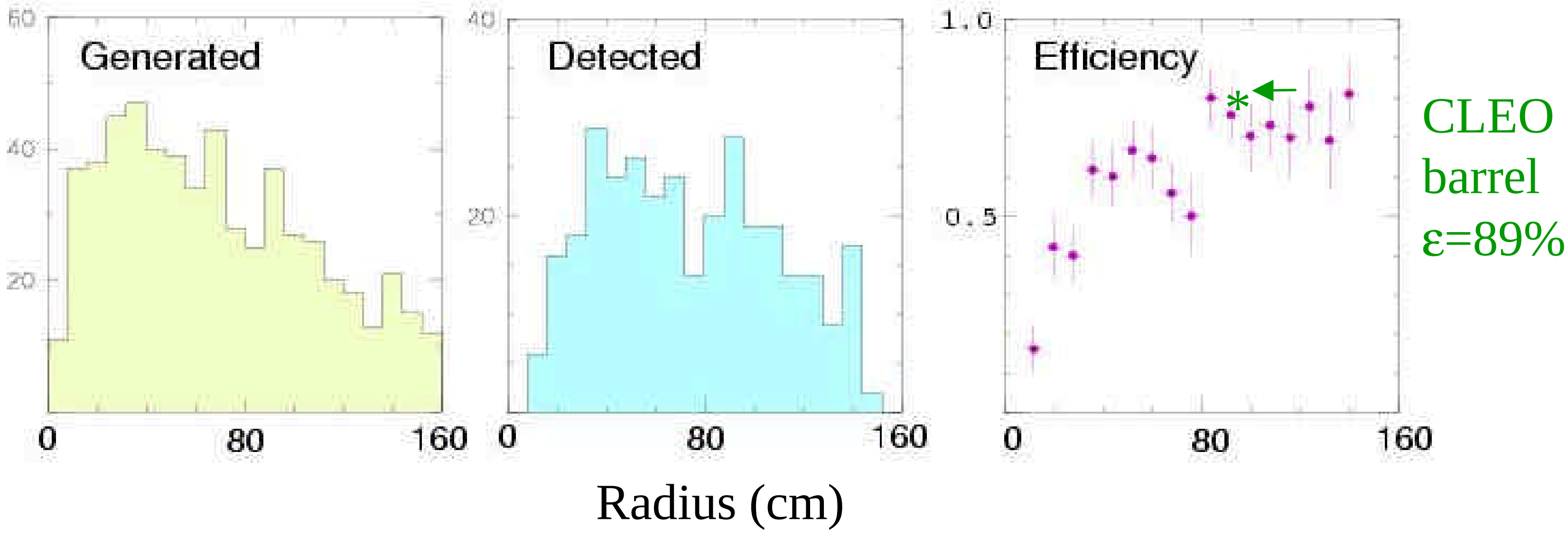


- Stochastic term 1.8% is good enough.
  - Original estimate of 1.6% was for different size crystals.

Geant 3 Simulations of $B \to \psi\eta$, $B \to \psi\eta'$



G3 Simulation of $B^0 \to K^{*0}\gamma$, $K^{*0} \to K^+\pi^-$

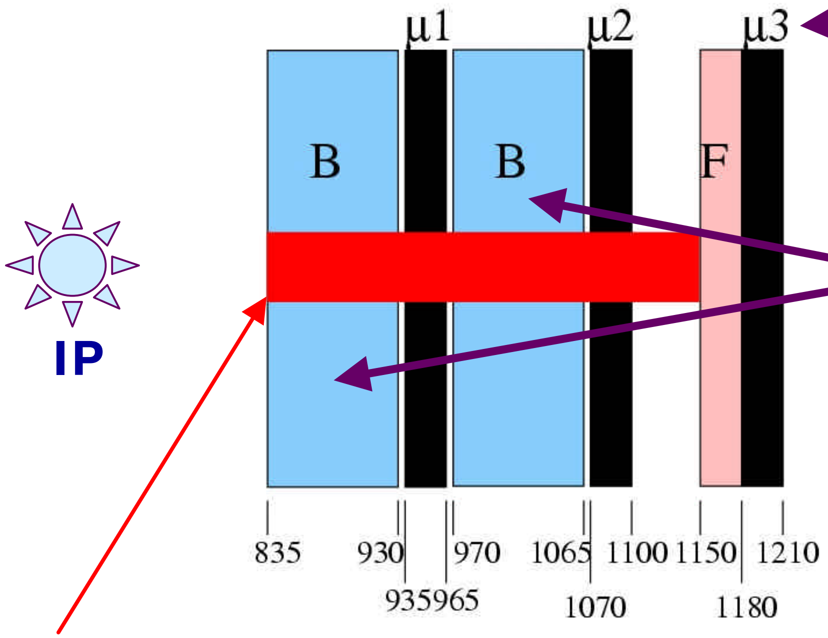


- + minbias events: Possion distributed mean = 2/beam crossing.
- Plots are for events in which the charged tracks pass all cuts.
- CLEO/BaBar/Belle-like performance in a hadronic environment.

The BTeV Muon System

- Two main functions:
  - Muon ID both for signal selection and for tagging.
  - Triggering:
    - Redundant trigger to test the detached vertex trigger.
    - More efficient for some states of particular interest such as $B \to J/\psi\ \eta$, $B \to J/\psi\ \eta'$, $B \to K^* \mu^+ \mu^-$ …
- Toroidal B field for momentum measurement in trigger.
- 3/8 inch dia. stainless steel proportional tubes.
- 36864 channels per arm.

Muon Vocabulary: Review

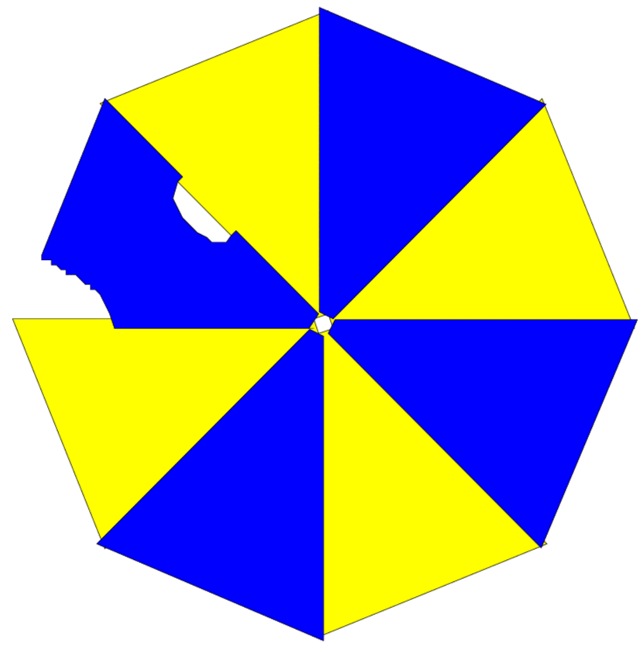


Three (3) ***stations*** of detectors

Toroids

Compensating Dipole

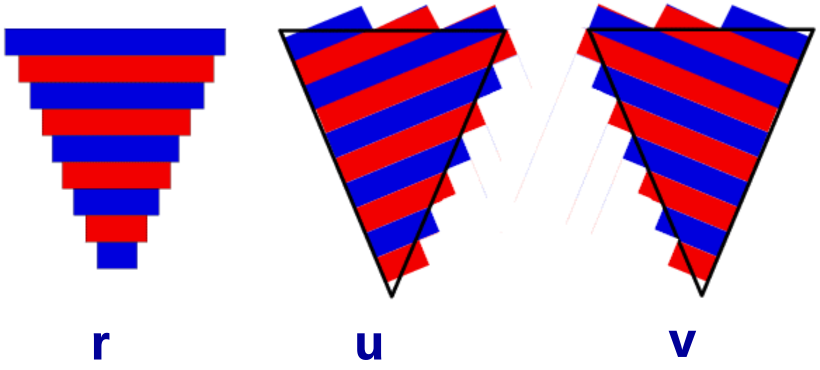
Beams Eye View reveals that each station is made up of overlapping ***octants***

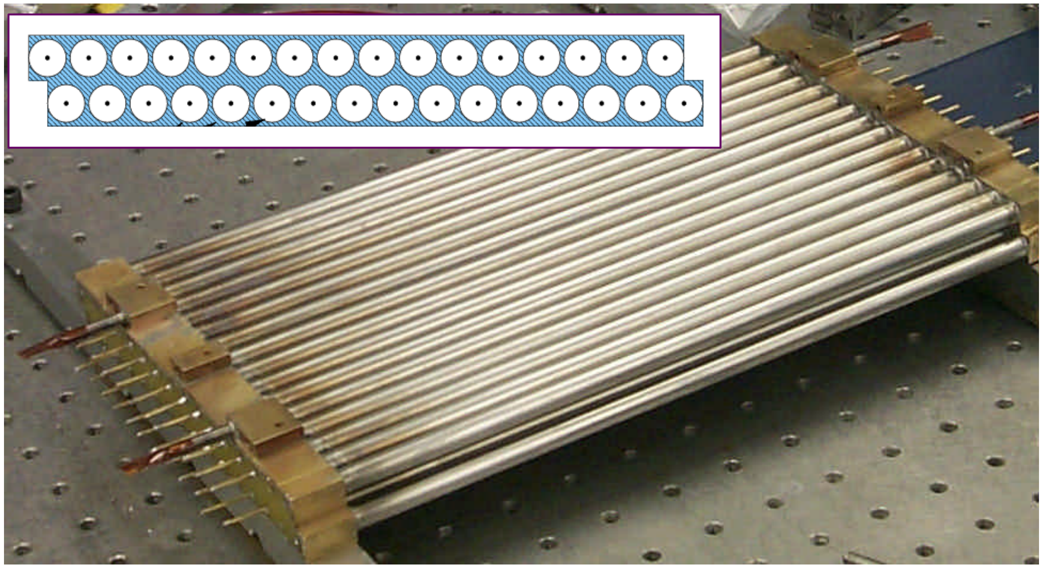


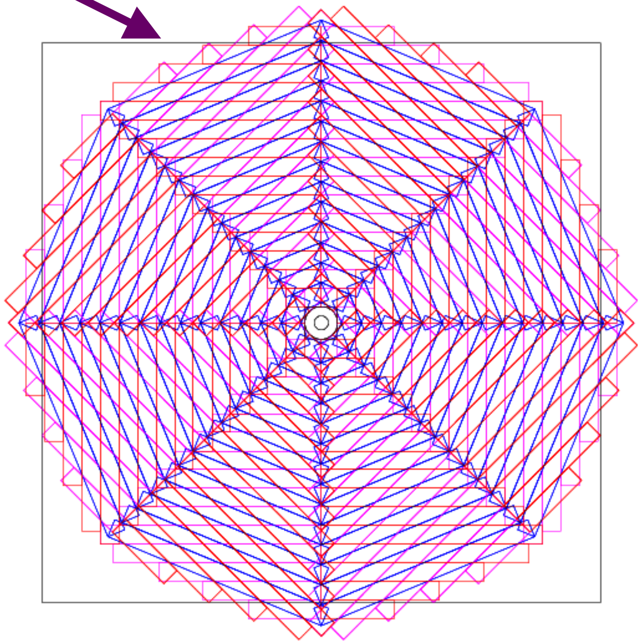
![BTeV logo]

…Muon Vocabulary: Review

- Each octant has four ***views*** *r*, *u*, *v*, *r*
- Basic building block is the ***plank*** of 32 prop tubes in a "picket fence" arrangement: 12 planks per octant view

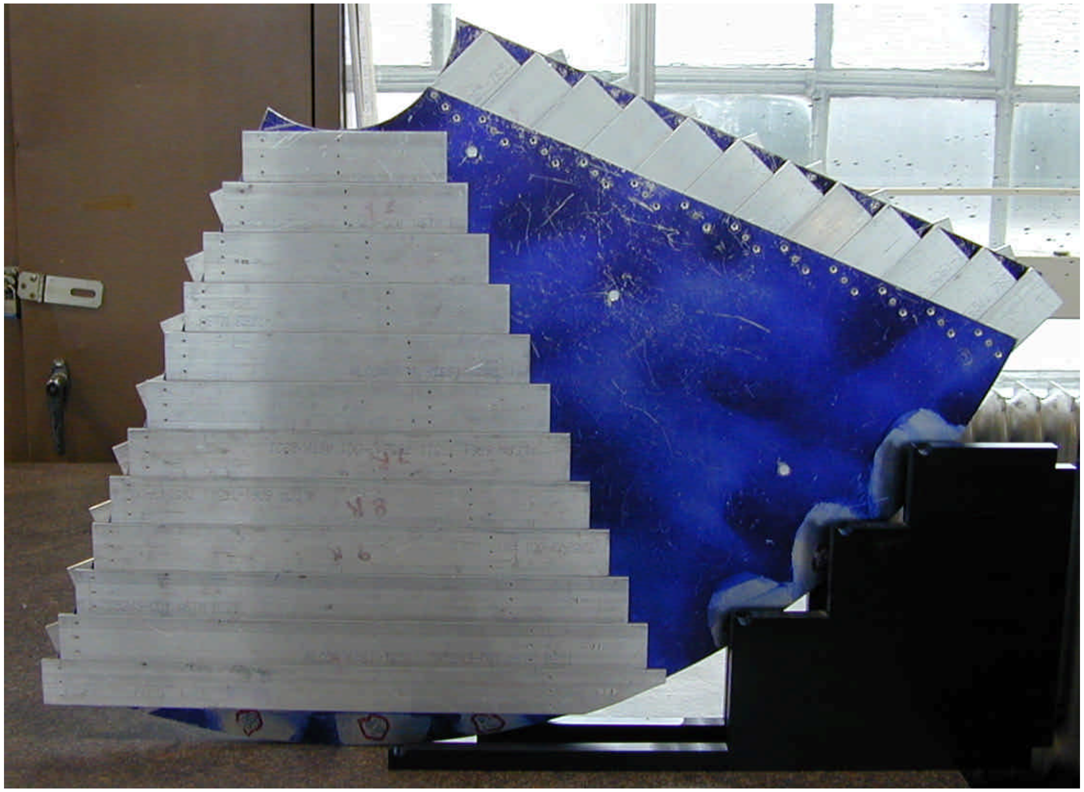




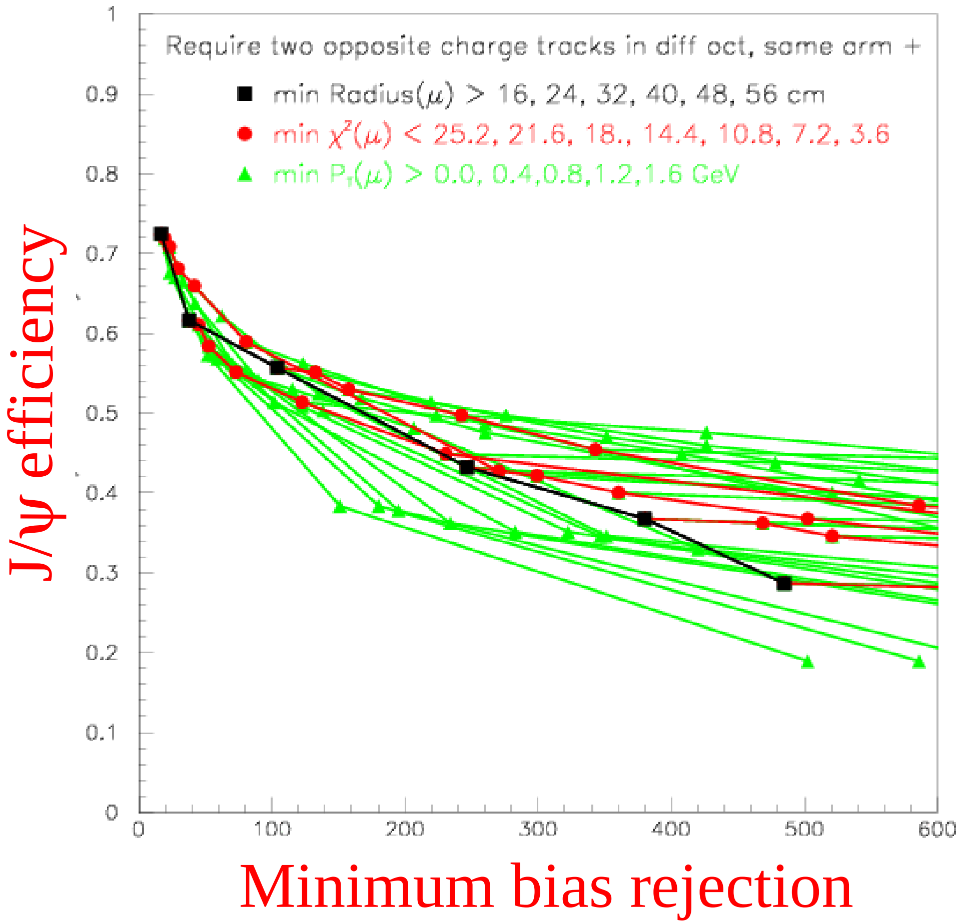


…Muon Vocabulary: Review

- Two octants form a ***quad***
- Quads will be built at institutions and delivered to FNAL
- Each quad will individually supported: it will be possible to install/remove a quad during run.
- Scale mock up built at Univ. of Illinois.



Simulation of Di-Muon Trigger



- Geant 3 simulation with 2 interactions per crossing.
- Signal events: $J/\psi \rightarrow \mu^+\mu^-$ from generic B decays.
- Find tracks standalone within each octant.
- Require two oppositely charged tracks in different octants + indicated cuts.
- J/ψ efficiency denominator has good reconstructable tracks, with p>5 GeV.

Simulation of DiMuon Trigger …

- In order to meet the DAQ bandwidth restricttions, we need a rejection of minimum bias events of around 1 to a few hundred.
- There is a wide range of possible operating points.

Flavor Tagging

- Methods in order of decreasing dilution:
  - Away side Kaon (Reasonably high efficiency).
  - Away side muon (Low efficiency).
  - Same side tag K (for B_s) and π (for B^0).
  - Jet charge (Large overlap with ASK and ASM).
- Still to come: away side electron.
- To remove overlaps, use the simplest method:
  - Poll methods in order of decreasing dilution.
  - Stop when a method gives an answer.

General Method for Tagging

1. Find kinematic variables correlated with the reconstructed B candidate (B_{CP}), eg: $\Delta\phi$, $\Delta\eta$, Q, $\Delta\chi^2_{RICH}$.
2. Form signal and BG probability distributions for these quantities (P_{signal} and P_{BG}).
3. For each tagging particle candidate, form a discriminant using the probability distributions derived in step 2.
4. Exclude candidates which fail the cut on this discriminant.
5. Form an event weighted charge to define sign of the tag, where N is the number of remaining candidates:

$$EWQ = \frac{\sum_i^N q_i * P_{signal}(i)}{\sum_i^N P_{signal}(i)}$$

Summary of Flavor Tagging

Tag Type	B_s		B_d	
	εD^2 Independent	eD2 Correlated	εD^2 Independent	εD^2 Correlated
Away Side K	5.8%	5.8	6.0%	6.0%
Away Side μ	1.3%	1.3	1.2%	0.8%
Same Side K(π)	5.7%	4.5	4.8%	1.4%
Jet Charge	5.4%	0.4	1.8%	1.0%
Total		12.1		9.2%
Nominal		13%		10%

Extra 1%
- Include electrons
- Allow for optimized use of all info.

Test Beam Plans

- Fall 2002 run at IHEP for EMCal requested.
- Fermilab plans to turn on the MTest test beam in fall 2002. BTeV detectors which will use it:
  - Pixels
  - Straws
  - Forward Silicon
  - RICH
  - Muon detectors

Summary and Conclusions

- BTeV will have excellent charged particle ID for all species of interest, e,μ,π,K,p, over most of the interesting momentum range.
  - Uses all of: RICH, EMCal, and Muon systems.
  - RICH: liquid radiator, C_5F_{12}, replaces aerogel.
- The calorimeter is capable of CLEO/BaBar/Belle-like performance, in both efficiency and energy resolution. Unprecedented in a hadron machine.
- Flavor tagging: εD^2 =10% B_d for and 13% for B_s.